MODELLING AND ANALYZING OF AN ACTIVE MAGNETIC BEARING

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ABSTRACT

This project presents a model of an active magnetic bearing which is design and analyzed using COMSOL Multiphysics and also analysis of an active magnetic bearing control system by using MatLab SimuLink. Magnetic flux from an active magnetic bearing is produced when a current is flowing in winding of the ferromagnetic core. To calculate this magnetic flux, the COMSOL Multiphysic is able to automatically calculate with just inserting the input of parameters. From this calculation, simulation of 2D magnetic flux density can be produce by following the step from COMSOL software guide. For control system of an active magnetic bearing, the Newton's law and the Kirchhoff's law are applied in order to obtain the right transfer function for the project. Graph resulting PID control for controlling the force, current and position is being plotted by comparing linear system and also non-linear system.

ABSTRAK

Projek ini membentangkan model aktif magnetik bearing yang di reka bentuk dan dianalisis menggunakan COMSOL Multiphysics dan juga analisis sistem kawalan aktif magnetik bearing dengan menggunakan MATLAB Simulink. Magnetik fluks daripada aktif magnetik bearing terhasil apabila arus elektrik terinduksi dengan penggulungan wayar tembaga kepada teras magnet yang merupakan bahan ferromagnet.. Untuk mengira fluks magnet ini, pengiraan diperlukan tetapi dengan bantuan COMSOL Multiphysic pengiraan ini secara automatik dikira dengan hanya memasukkan input parameter ke dalam COMSOL Multiphysic ini. Dari pengiraan ini, simulasi 2D ketumpatan fluks magnet boleh terhasil dengan hanya mengikuti beberapa langkah dari panduan perisian COMSOL. Bagi sistem kawalan aktif magnetik bearing, undang-undang Newton dan undang-undang Kirchhoff adalah penting untuk mendapatkan rangkap pindah yang akan digunakan. Graf akan terhasil melalui kawalan PID di dalam MatLab yang akan mengeluarkan graf bagi membandingkan perbezaan sistem linear dan juga sistem bukan linear.

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CHAPTER 1

INTRODUCTION

1.1 Background Of Project

It is an old dream of mankind to levitate a body hover without any contact by using magnetic forces. As early as 1842, the British minister and nature philosopher, Samuel Earnshaw (1805 - 1888), examined this question and stated a fundamental proposition known as Earnshow's theorem. The essence of this theorem is that it is impossible for an object to be suspended in a stable equilibrium purely by means magnetic or electrostatic forces. First technical applications of levitation by magnetic field were proposed in 1937, when Kemper applied for a patent for a hovering suspension, while Beams and Holmes were working on electromagnetic suspension. This experiment was the predecessor of the later magnetically levitated vehicles. The most familiar levitation vehicle nowadays is the MAGLEV (derived from magnetic levitation), which uses the electromagnetic principle, is suspended without any contact by several magnets from the iron track. Later, in the sixties a principle of magnetic bearings was used in space technology for the magnetic suspension of momentum-wheels to control the attitude of satellites. First industrial applications appeared in the late seventies mainly for turbines and for high-speed machine tools. Because of the magnetic bearing offer a novel way to solve classical problems of rotor dynamics by suspending a spinning rotor with no contact, wear and lubrication, and controlling its dynamic behaviour

An Active Magnetic Bearings (AMBs) is largely used nowadays in many industries, mostly in oil and gas industry since it can sustain high temperature with a constant high speed. Active magnetic bearings (AMBs) are experiencing an increased use in many rotating machines (e.g., compressors, milling spindles, flywheels, etc.) as an alternative to conventional mechanical bearings such as fluid film and rolling element bearings. An AMB provides a non-contact means of supporting a rotating shaft through an attractive, magnetic levitation force. The magnetic force is generated or controlled by passing an electric current through a coil wound around a stator made of ferromagnetic material (i.e., an electromagnet).

Due to the non-contact nature of the bearings and rotor, AMBs have the unique ability to suspend loads with no friction, eliminate wear, allow the operation of rotors at higher speeds, and operate under environmental conditions that prohibit the use of lubricants. Furthermore, since AMBs can be actively controlled, they offer other advantages over mechanical bearings such as eliminating rotor vibration through active damping, adjusting the stiffness of the suspending load, compensating for rotor misalignment and changes in rotor speed, and providing an automatic rotor balancing capability.

For my project, there are 2 main software that I used to design and analyse of an active magnetic bearing which is Comsol Multiphysics to analyse the design of an active magnetic bearing and MatLab to see how an active magnetic bearing work by using the principle of magnetic levitation.

COMSOL Multiphysics is a finite element analysis, solver and Simulation software / FEA Software package for various physics and engineering applications, especially coupled phenomena, or multiphysics. COMSOL Multiphysics also offers an extensive interface to MATLAB and its toolboxes for a large variety of programming, preprocessing and postprocessing possibilities. The packages are cross-platform (Windows, Mac, Linux). In addition to conventional physics-based user interfaces, COMSOL Multiphysics also allows for entering coupled systems of partial differential equations (PDEs). The PDEs can be entered directly or using the so-called weak form (see finite element method for a description of weak formulation). An early version (before 2005) of COMSOL Multiphysics was called FEMLAB.

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. Typical uses include:

1. Math and computation
2. Algorithm development
3. Modeling, simulation, and prototyping
4. Data analysis, exploration, and visualization
5. Scientific and engineering graphics
6. Application development, including Graphical User Interface building

MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. This allows you to solve many technical computing problems, especially those with matrix and vector formulations, in a fraction of the time it would take to write a program in a scalar non-interactive language such as C or FORTRAN. The name MATLAB stands for matrix laboratory. MATLAB was originally written to provide easy access to matrix software developed by the LINPACK and EISPACK projects, which together represent the state-of-the-art in software for matrix computation. MATLAB has evolved over a period of years with input from many users. In university environments, it is the standard instructional tool for introductory and advanced courses in mathematics, engineering, and science. In industry, MATLAB is the tool of choice for high-productivity research, development, and analysis. MATLAB features a family of application-specific solutions called toolboxes. Very important to most users of MATLAB, toolboxes allow you to learn and apply specialized technology. Toolboxes are comprehensive collections of MATLAB functions (M-files) that extend the MATLAB environment to solve particular classes of problems. Areas in which toolboxes are available include signal processing, control systems, neural networks, fuzzy logic, wavelets, simulation, and many others.

1.2 Problem Statement

Nowadays, bearing is used widely in a rotating machines (e.g., compressors, milling spindles, flywheels, etc.) to support the load. Mechanical bearing is used in many applications but it creates friction loss. For example in high temperature place like turbine at oil and gas, the bearing will get wear easily and need to change them often due to the high temperature. Beside that for a place which use vacuum a normal bearing such as mechanical bearing can't perform here due to the vacuum suck air out from the place which mean oil from bearing will get suck out and make the friction between shaft and bearing will be high. The solution here is with an Active Magnetic Bearings (AMBs) the friction that create will be gone since an Active Magnetic Bearings (AMBs) is a no contact bearing which suspended by an electromagnet.

There are several questions on how to make the Active Magnetic bearings (AMBs), What is the type of core need to be used as a stator and what is the type of windings need to be used to produce an electromagnetic field. Beside that a duly formulae of megnetomotive force is needed to know whether it is sufficient to float/balance the shaft in the middle of stator/core.

This study investigated the entire problem about designing and analyse of an active magnetic bearing such as what is the type of core needed, how much windings need to be used, how much current flow need for each coil, and also how the system to levitate is working.

1.3 Objective

To develop and simulate a model of an active magnetic bearing.

To design and simulate a control system for controlling the current to levitate an object.

To analyze the active magnetic bearing.

1.4 Scope of Project

This thesis specifically has three scopes.

(i) Design an Active Magnetic which can produce the sufficient magnetic flux density to levitate an object.
- There will be 8 poles for the windings to be attached according to the north and south which will produce the magnetic flux.

(ii) Program a control system in Matlab to see how an active magnetic bearing works.
- There will be several transfer function which based on Newton Law's and Kirchhoff's Current/Voltage Law.

(iii) Design a circuit for levitation
- Circuit will consist of a component which will act as a Gate to allow several current flow to activate the magnetic bearing and also a sensor which will be suitable to sense current.

1.5 Thesis Overview

Modeling and analyzing of an active magnetic bearing final thesis is a compilation of 6 chapters that contains and elaborates specific topics such as the Introduction, Literature Review, Methodology, Architecture, Result and Analysis, Conclusion and Further Development that can be applied in this project.

Table 1.1: Thesis overview with chapters

Chapters	Content	Remarks
Chapter 1	Introduction	Basically about the background and introduction of this project.
Chapter 2	Literature Review	Describe about the literature review for the development of the solar based monitoring workstation cited from related sources.
Chapter 3	Methodology	Discuss on the full methodology of this project
Chapter 4	Systems Architecture	Discuss about the architecture of the project that consist of the hardware design and the software implementation.
Chapter 5	Results and Data Analysis	Discuss all the results obtained and the limitation of the project. All discussions are concentrating on the result and performance of the Active Magnetic Bearings (AMBs)
Chapter 6	Conclusion	Discuss the conclusion and further development of the project.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter explains the capabilities and features of the existing Active Magnetic Bearings (AMBs) described in the literature that were reviewed. The aim of this literature review is to acquire great understanding of how to design an Active Magnetic Bearings to support a rotating load that have been implemented and are already use in similar situation which will be useful for my research. The suitable features examined will be considered to be incorporated into the proposed system.

The objectives of this chapter are:

- To understand how an Active Magnetic Bearings (AMBs) work
- To select the appropriate components, device or circuit related to this project.
- To understand the formulae and transfer function for this project.

2.2 Active Magnetic Bearings (AMBs)

The term **"bearing"** comes ultimately from the verb "to bear" and a bearing is thus a machine element that allows one part to bear another. A bearing is any of various machine elements that constrain the relative motion between two or more parts to only the desired type of motion. This is typically to allow and promote free rotation around a fixed axis or free linear movement; it may also be to prevent any motion, such as by controlling the vectors of normal forces. Bearings may be classified broadly according to the motions they allow and according to their principle of operation, as well as by the directions of applied loads they can handle. But the problem with normal mechanical bearing is that it had a friction loss and also easy to get wear which will be need to change more often. With **Active Magnetic Bearings (AMBs)** is the best solution which can give a zero friction by having a no contact to the rotor/shaft. Besides that, AMBs can operate in high speed with a high efficiency while giving low noise. Magnetic bearing is an active system, thus it provides several advantages over a passive one. The controller can compensate unbalance and control the rotor behaviour actively at critical speeds. System monitoring is then possible by using the AMB as a sensor, which provides indications about the changes in shaft dynamics. This system diagnosis enables to reduce the maintenance cost by increasing the intervals between engine services.

2.3 The Shape design of the Active Magnetic Bearing (AMB) stator

According to Adam Pilat (2010), Computer-aided design (CAD) software in the modeling process is the standard design method used to design the shape of the AMB bearing core. The designs consist of graphical primitives like lines and arcs with fixed properties. There are 2 method for choosing the design which is based on mathematical analysis and representation of the AMB stator by curve. There are many main components of the AMB which need to be considered in designing AMB which are stator for windings, coils, power actuators, control system with appropriate control strategy and rotor as a target object of control.

The main focus which illustrate by Adam Pilat is the stator construction which has a number of rectangular poles where coil windings are mounted. The connected coils and stator core compound an electromagnet that precisely generates attractive force acting on the rotor under controller supervision which is a microcontroller. The stator is manufacture with laminated metal plates produced in the cutting process using blanking die method, laser tools or CNC machines. The design procedure requires analytical and numerical calculations of the electromagnetic forces beside tend to be optimal in the case of pole numbers and their location. There are 2 designs which being consider to design AMB stator based on curves which is AMB pole represented by 2nd order curves and AMB poles represented by 3rd order curves.

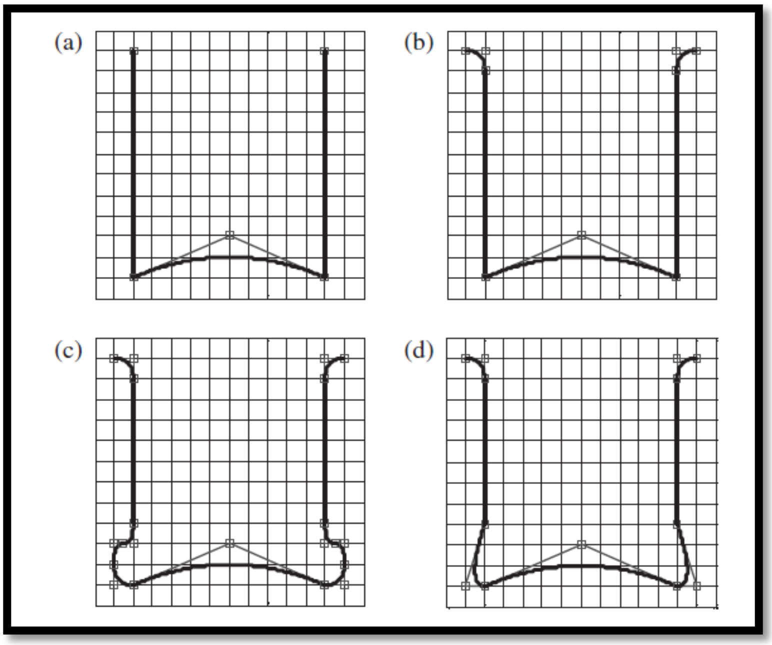

Figure 2.1: AMB pole represented by 2nd order curves.

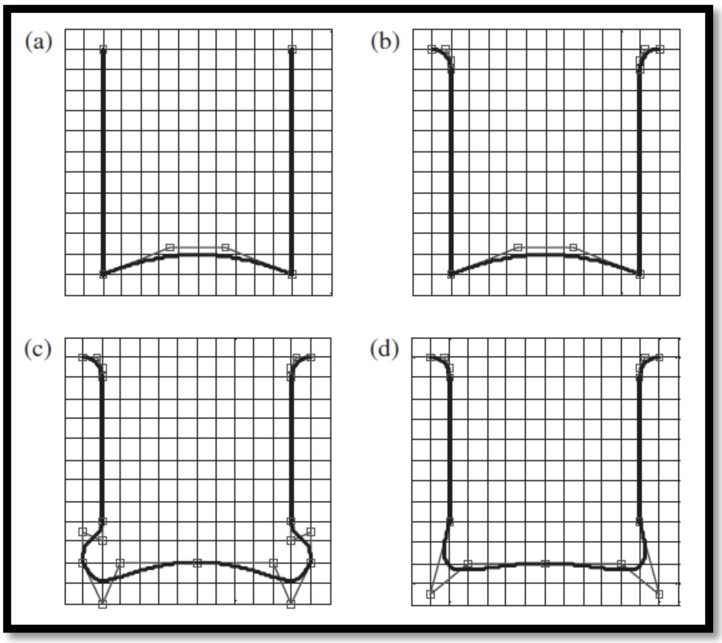

Figure 2.2: AMB pole represented by 3rd order curves.

With the presented design method of the stator shape, it opens a news a new features for modeling, optimization and analysis of the magnetic field interaction in the AMB based machinery. The highest accuracy gives is by the 3rd order curve. Figure 2.3 below show the complete form of the AMB stator shape.

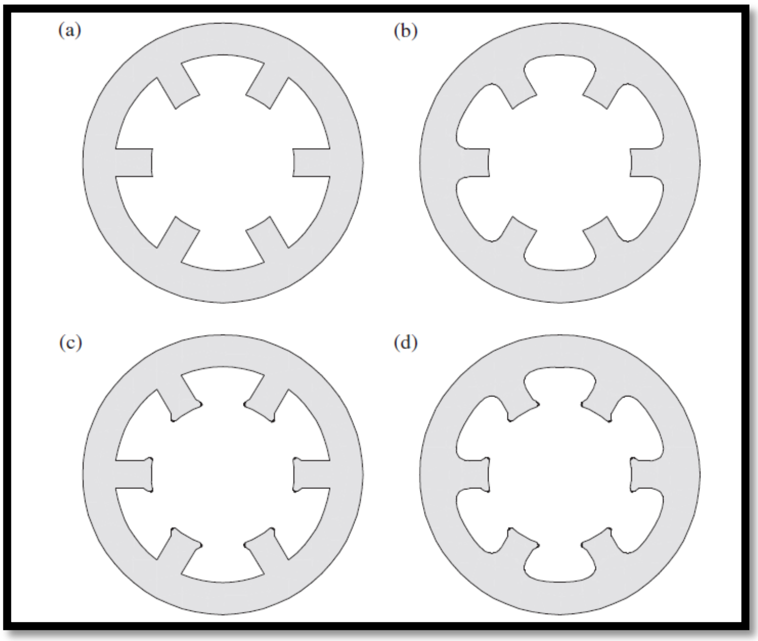

Figure 2.3: AMB stator with six poles (a) standard form, (b) rounded external pole part, (c) rounded internal pole part, and (d) proposed form with rounded corners.

2.4 How Active Magnetic Bearings (AMBs) system work?

How it works? **H. Habermann and G. Liard (1980)** said that Actidyne active magnetic bearing system is the basic principle of design and operation. The advantages of this system are due to the absence of mechanical contact, obviating the need for lubrication, and to the high accuracy of shaft position. The idea of making a suspension of a rotating shaft in a magnetic field without mechanical contact and without lubrication is an old idea from 1842 which was introduced by Earnshaw to make a passive magnetic suspension and the first description of a totally active magnetic suspension system was only issued in 1957 as a French patent assigned to the Hispano-Suiza Company. During the last ten years electric control has been sufficiently developed to make the design of an active magnetic for industrial application is possible. Industrial application, particularly for large machinery with shafts weighing several tons.

The principle of the Actidyne active magnetic bearing system is that the body is supported and the rotor is held in the desired position relative to the stationary body while the stator by electromagnetic control. The sensors used for this system is a highly accurate inductive sensors to monitor the position continuously. After amplification, currents are induced in the windings of the electromagnets of the stator and the magnetic and magnetic force is produced serve to restore the rotor to the desired position so that stable centering is achieved. The interaction between the bearing and the control is shown in figure below

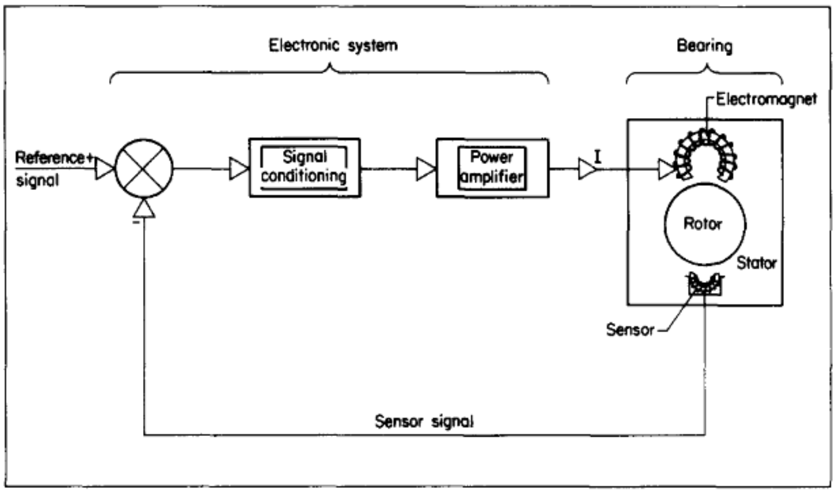

Figure 2.4: Operation of control loop

According to H. Habermann and G. Liard also the principle operation of a radial bearing includes four electromagnets and four sensors. Ferromagnetic lamination without windings is used for the rotor and is supported by magnetic forces. The rotor will keep it in the desired position. Figure below show the example:-

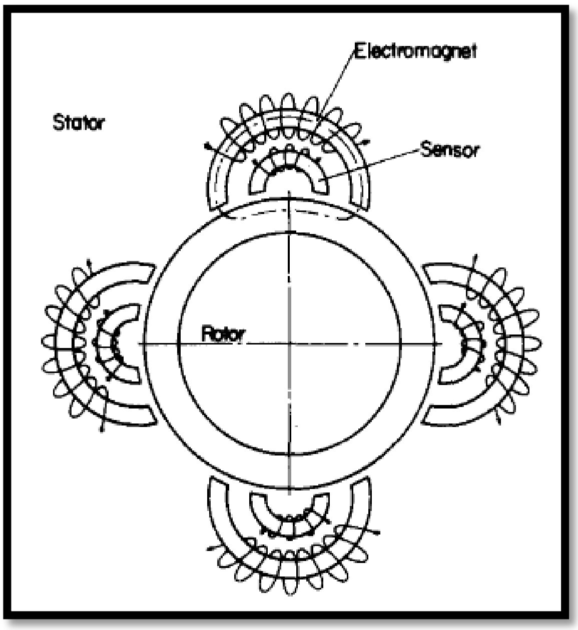

Figure 2.5: Radial bearing includes four electromagnets and four sensors.

According to **Hada Chang and Sung-Chong Chung (2002)**, the size, the controller and power amplifier affect the performance of active magnetic bearing (AMB). Good stiffness, damping and stability, simultaneous consideration on the AMB itself and characteristics of the controller and the power amplifier should be required to design optimal AMB systems. A radial active magnetic bearing (AMB) system supports a rotor without having any mechanical contact by electrically controlling the electromagnetic force. The rotor will be floated in the air gap and get rid of the mechanical breakdown caused by wear or friction and there is no need for lubrication and sealing which will be save on money and time of workers. AMB system can be designed so that it has adjustable stiffness and damping. A high-speed and high-precision rotating motion can be implemented and this is why AMB systems referred to have big potentiality in the industry. Figure below show the schematic diagram of a single axis AMB system which is designed by the author:-

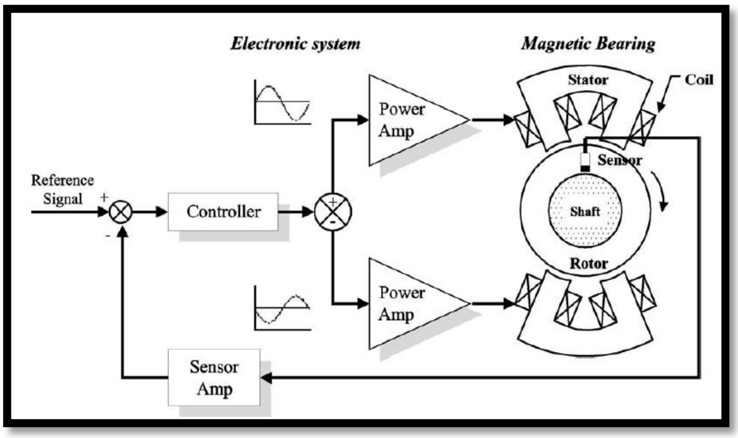

Figure 2.6: Schematic diagram of a single axis AMB system.

2.5 The Hardware parts

There are 6 parts in building hardware for Active Magnetic Bearings (AMBs) said **Dr. Luc BURDET (2006)**. The first main part is the core for AMB. Iron core is the best material to be used. What is an Iron core? Iron core is a material conducting the magnetic field to the air gap. It's magnetic permeability and its magnetic saturation has to be high. Eddy current losses is need to be minimize, In order to minimize it, the core usually consist of insulated lamination sheets. Next is the Windings, The current through the winding is the source of magnetic field. It is made of an insulated conductor wound on the soft magnetic core. In order to improve the efficiency of the AMB, the conductor has to have a low electrical resistance and must be wound with a high fill factor. The best material considered to be the best for windings is nickel-copper or copper. For the author, it used different type of windings since it need the best material to be handle a high temperature for the research.

The 3rd parts being used is the rotor. The rotor, in standard constructions, is realized with a lamination packet shrinked on a non-magnetic shaft. Tight manufacturing tolerances are needed in order to avoid unbalances in the weight of shaft. It is important to make sure the mechanical property of the rotor lamination is good this is because to overcome the centrifugal stress due to high speed rotation. The 4th part is the position sensors. Since AMBs are actively controlled regarding to the sensor signal, the control performance strongly depends on the sensor performance. Other types of sensor usually used in AMBs are inductive, eddy current, capacity and optical displacement sensors.

Last but not least, a microcontroller. Nowadays controllers are mainly based on digital technology. Great flexibility and high computation is provided by the controllers. Digital controllers enable principally an adaptative control, unbalance compensation and provide a great tool for system diagnosis. AMBs are controlled in a close –loop. Different method such as PD or PID, optimal output feedback or observer based state feedback is in use. Lastly is the Power Amplifiers. Why use Power Amplifiers? It is because amplifiers convert the control signal from PID hardware into control currents. Switching amplifiers are usually used because of their low losses. The amplifier is often the limitating component in an AMB system.

2.6 SUMMARY

As a conclusion Active Magnetic Bearing (AMB) is the solution to reduce the cost for changing a bearing if they got wear and having a zero friction. Besides that, AMB can operates in high-speed and high-temperature place which allow oil and gas industries which use turbines to use AMB as their new bearing. Mechanical bearing will only allow more money spend and more time wasting for workers to change it regularly. There are many Computer Aided Design (CAD) programs that can be used in modeling the active magnetic bearing such as CATIA, Solidwork, AutoCAD and Comsol MultiPhysic. MatLab is the best solution in analysis of control system.